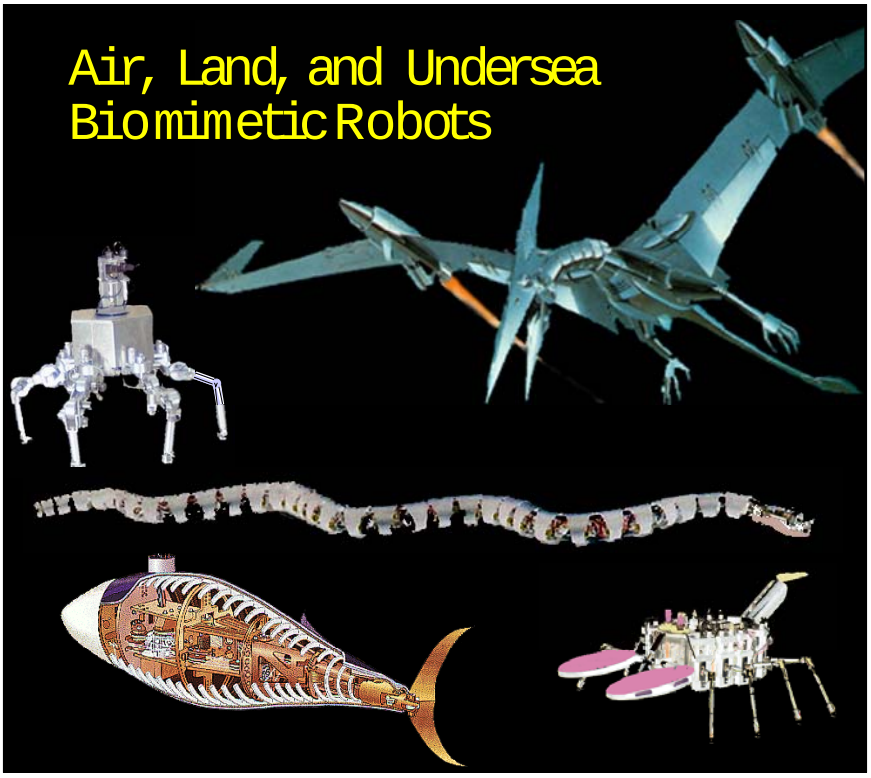
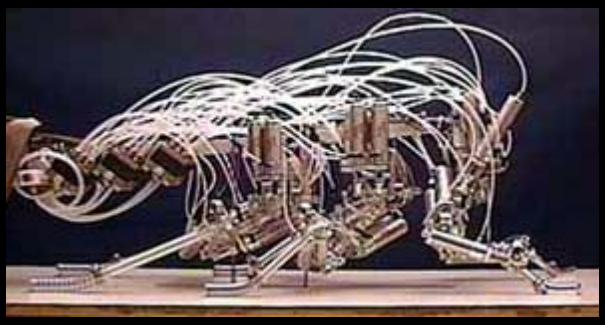
Georgia Tech Research Institute

Intelligent Planetary Biomimetic Robotic Agents

Air, Land, and Undersea Biomimetic Robots



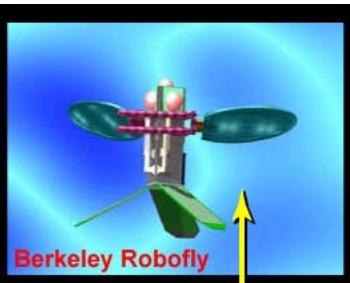
Some U.S. Biomimetic Crawling and Swimming Concepts



Pneumatic Cylinder-Driven Roach

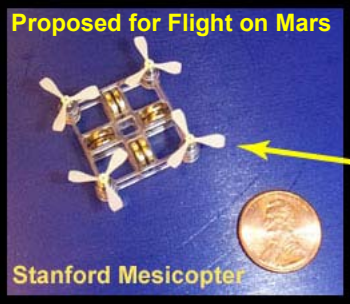
Tendon-Driven Fish

Some U.S. Biomimetic Flyers and Competing Conventional Concepts

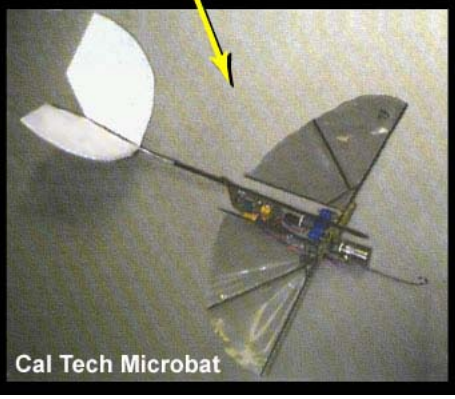


Solar Powered

Proposed for Flight on Mars



Battery Operated



European Researchers are also Working on Biomimetic Flapping Wings

For example, the German Ingenieur-büro in Düsseldorf is working with the University Saarbrücken to develop a 2:1 scale prototype Bee wing operating at frequencies up to 150 Hz. This wing is kinematically similar to that of a bee, taking into account rotational modes and resonance.

UK researchers at Department of Aerospace Power and Sensors at Cranfield University, Shrivenham campus are similarly working on kinematically correct wing flappers.

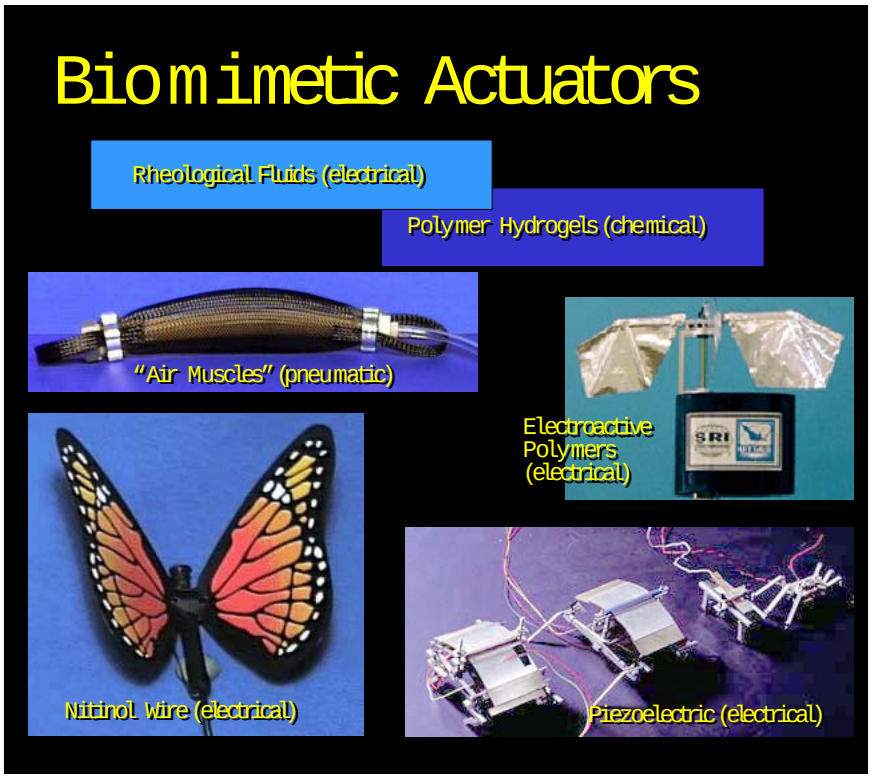
Replicating the degrees of freedom of the insect wing becomes more difficult to actuate as the scale is decreased.

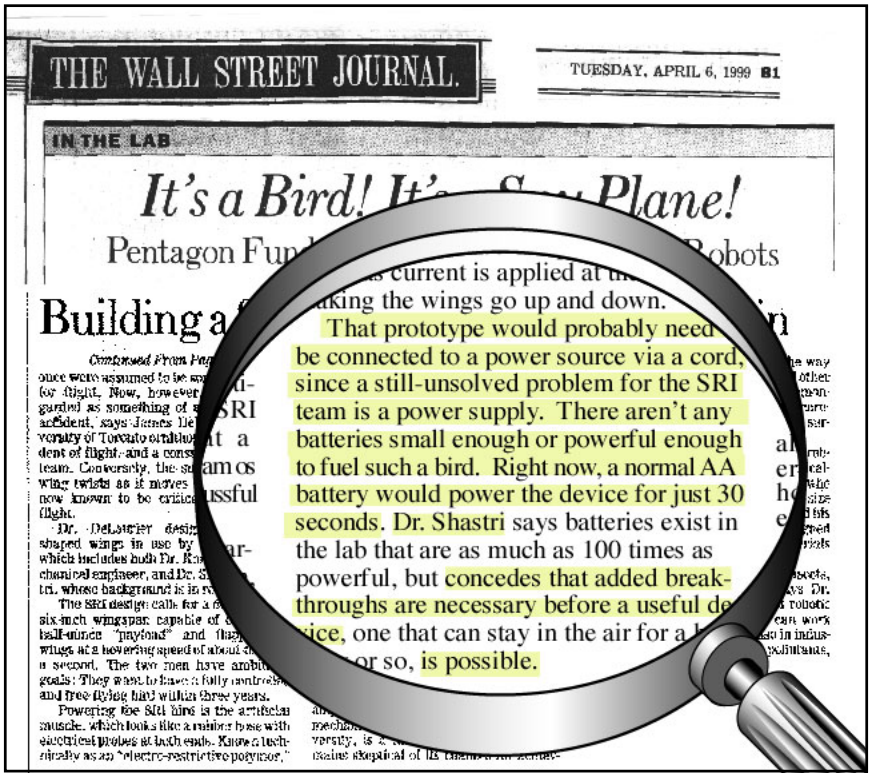
The "Big Three"

Three major problem areas associated with bird or insect-like (size constrained) machines:

- Non-Scaling Items
- Energy Storage
- Propulsion

04 MICHELSON




THE WALL STREET JOURNAL. TUESDAY, APRIL 6, 1999 B1

IN THE LAB

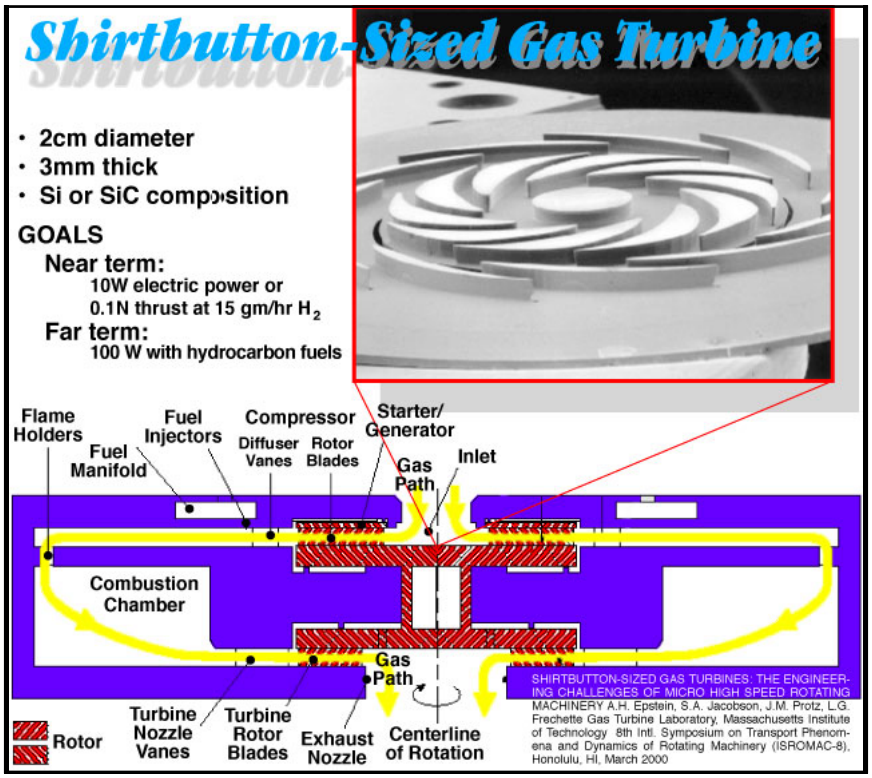
It's a Bird! It's ... Plane!

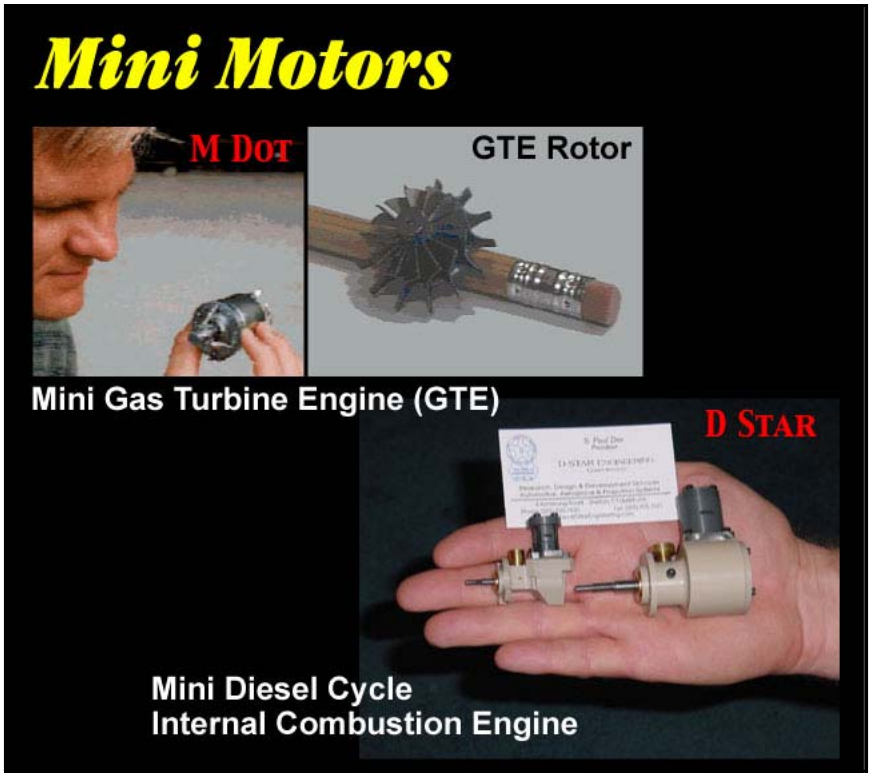
Pentagon Fun... ...obots

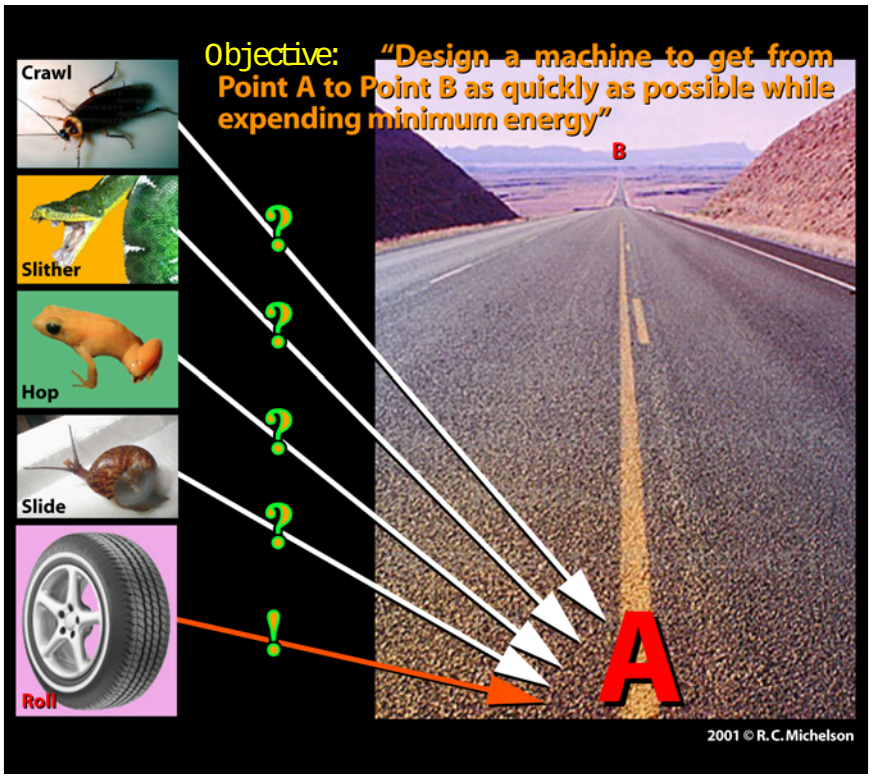
Building a ...

...current is applied at th... ...aking the wings go up and down.

That prototype would probably need be connected to a power source via a cord, since a still-unsolved problem for the SRI team is a power supply. There aren't any batteries small enough or powerful enough to fuel such a bird. Right now, a normal AA battery would power the device for just 30 seconds. Dr. Shastri says batteries exist in the lab that are as much as 100 times as powerful, but concedes that added breakthroughs are necessary before a useful de... ...vice, one that can stay in the air for a h... ...or so, is possible.


Shirtbutton-Sized Gas Turbine
• 2cm diameter
• 3mm thick
• Si or SiC composition
GOALS
Near term:
10W electric power or
0.1N thrust at 15 gm/hr H_2
Far term:
100 W with hydrocarbon fuels
Flame Holders
Fuel Manifold
Fuel Injectors
Compressor
Diffuser Vanes
Rotor Blades
Starter/ Generator
Gas Path
Inlet
Combustion Chamber
Gas Path
Rotor
Turbine Nozzle Vanes
Turbine Rotor Blades
Exhaust Nozzle
Centerline of Rotation
SHIRTBUTTON-SIZED GAS TURBINES: THE ENGINEERING CHALLENGES OF MICRO HIGH SPEED ROTATING MACHINERY A.H. Epstein, S.A. Jacobson, J.M. Protz, L.G. Frechette Gas Turbine Laboratory, Massachusetts Institute of Technology 8th Intl. Symposium on Transport Phenomena and Dynamics of Rotating Machinery (ISROMAC-8), Honolulu, HI, March 2000

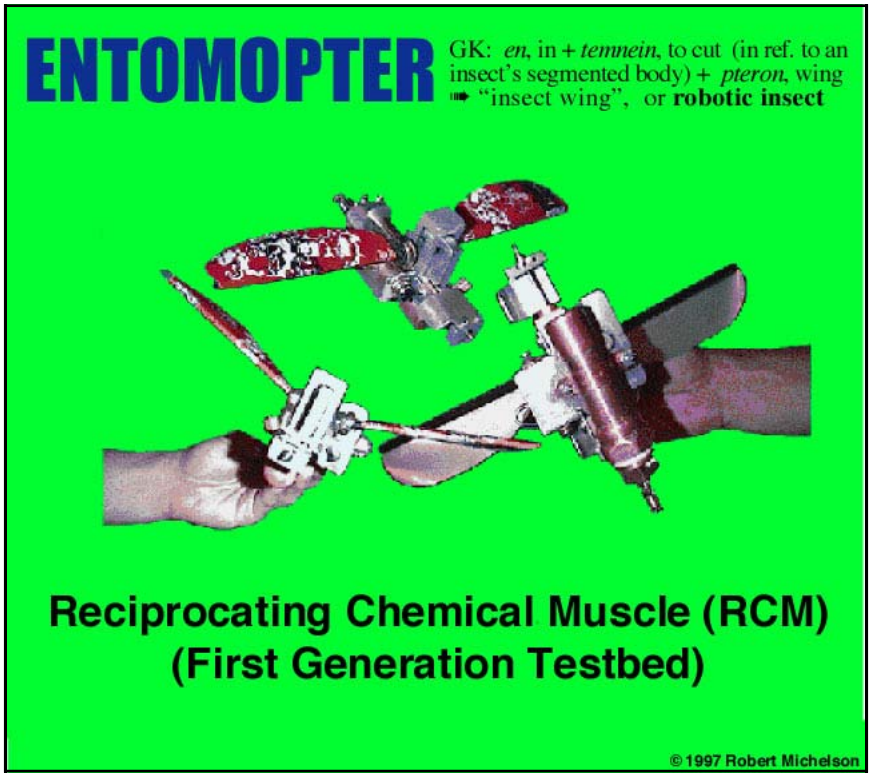

Mini Motors
M Dot
GTE Rotor
Mini Gas Turbine Engine (GTE)
D Star
Mini Diesel Cycle
Internal Combustion Engine

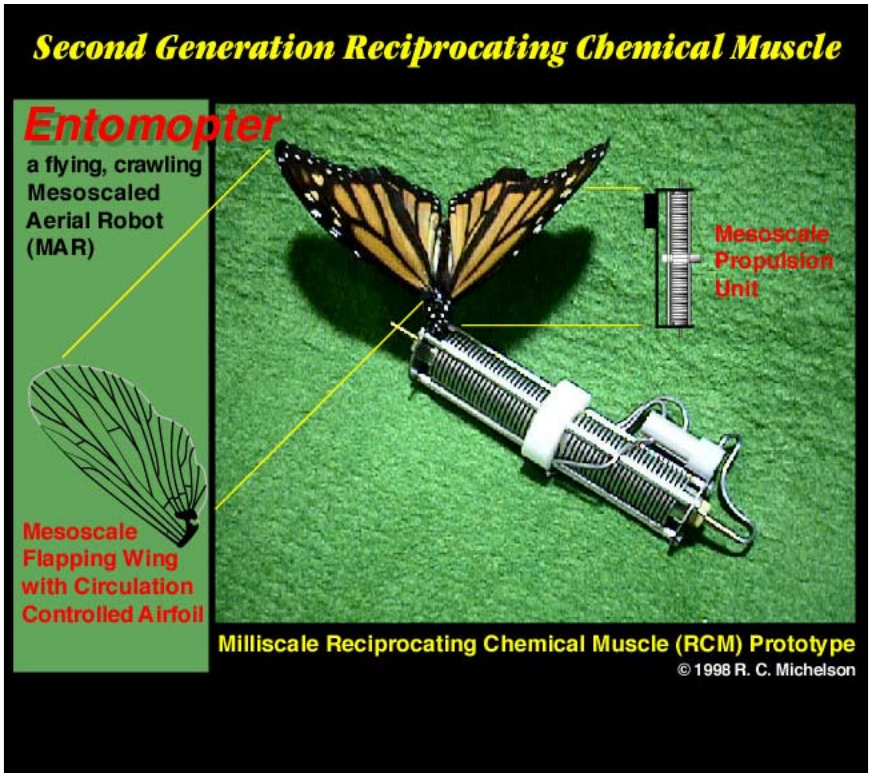


Michelson's Aphoristic Decalogue of Flight Biomimetics

1. Biomimetics is a good starting point.
2. Strict adherence to biomimetic "guidance" can result in non-optimal performance solutions or unmanufacturable systems.
3. Thinking outside the box is always desirable, but sometimes optimal solutions fall within "the box".
4. Biomimetic point solutions may not be practical apart from the "system". (They typically work in concert with each other synergistically).
5. Simply being able to beat wings isn't enough— one must be able to develop the power necessary to fly.
6. Biomimetic flapping is structurally complex, leading to difficulties in flight control, manufacturing, and weight.
7. Means to control stability and to navigate are non trivial.
8. Poor integration of all flight systems leads to unmanageable weight.
9. Designs which do not capitalize on resonance waste energy.
10. The average power density for present battery technology is marginal for small scale flapping wing flight.


Reciprocating Chemical Muscle
(RCM) Testbed
©1997 Robert Michelson
and Stanley Leary


ENTOMOPTER
GK: *en*, in + *temnein*, to cut (in ref. to an insect's segmented body) + *pteron*, wing
➠ "insect wing", or **robotic insect**
Reciprocating Chemical Muscle (RCM)
(First Generation Testbed)
©1997 Robert Michelson


Second Generation Reciprocating Chemical Muscle
Entomopter
a flying, crawling Mesoscaled Aerial Robot (MAR)
Mesoscale Propulsion Unit
Mesoscale Flapping Wing with Circulation Controlled Airfoil
Milliscale Reciprocating Chemical Muscle (RCM) Prototype
© 1998 R. C. Michelson

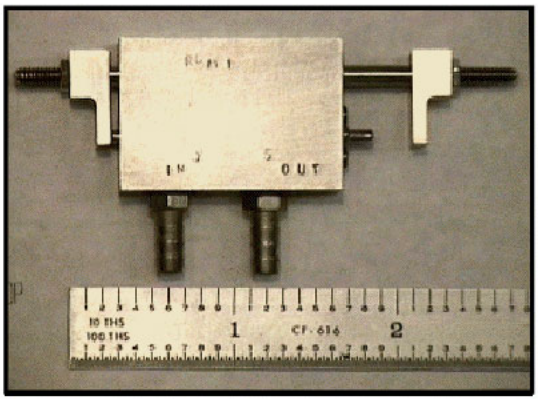
RCM Components Description

MAR
Mesoscaled Aerial Robot

Third Generation RCM

Function:
Assembly Body with Integrally-Drilled Porting and Gating

- Body made of SS347, annealed.
- Port barbs; plated brass.

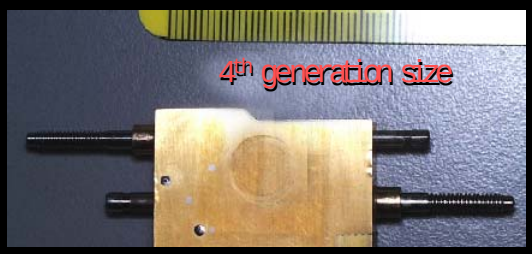


RCM BLOCK (assembled unit)

DARPA DSO Georgia Tech • ETS Labs • University of Cambridge Georgia Tech Research Institute

4th Generation RCM

Funded under the Air Force Revolutionary Technology Program

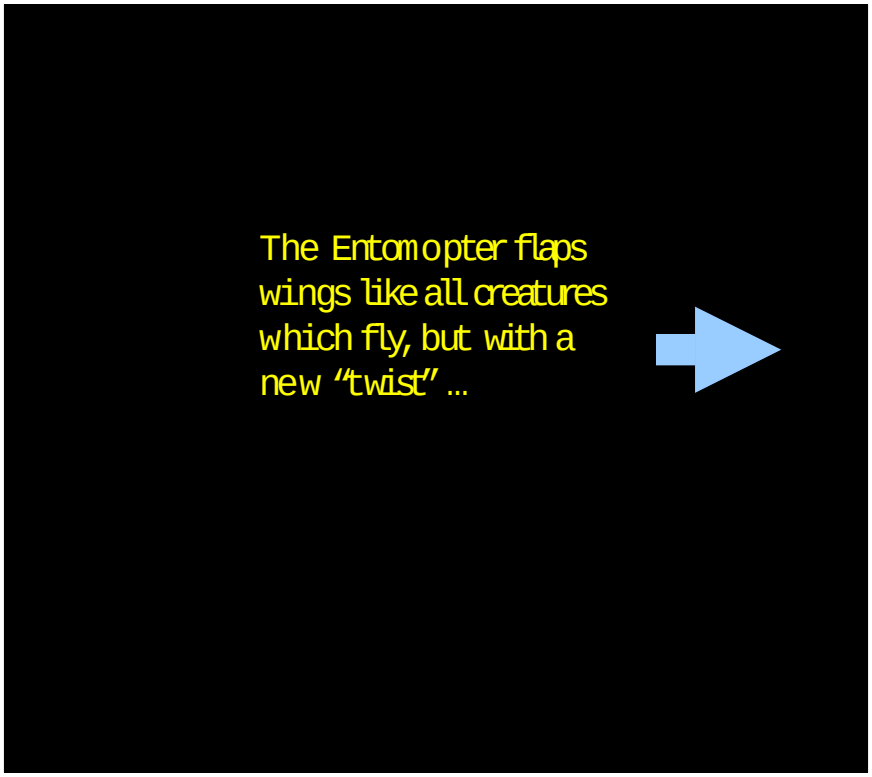


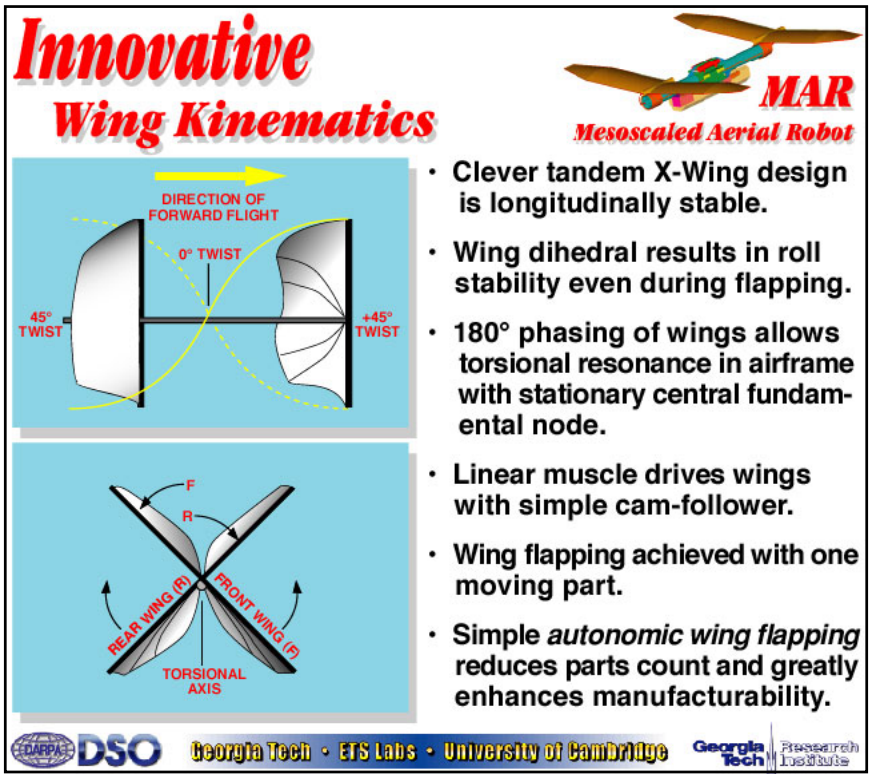
Flyable Terrestrial Size is 2.5 smaller

Vibrationless Bi-directional longitudinal actuation

Stroke		0.266 inch
Maximum Operating Gas Temperature	1364 °F	
Frequency Response (strokes/second)		15 - 68 Hz
Static Stroke Force	17.8 oz	
Duty Cycle		100%


Fuel Storage Cartridge
Wing modeled after that of the Hawkmoth (*Manduca sexta*)
Front
Reciprocating Chemical Muscle Actuator
Gross wt. = 50 grams
Fuel wt. = 25 grams
Payload = approx. 10 grams
15 cm wingspan Entomopter
Georgia Tech Research Institute
Copyright © 2001 R. C. Michelson
Kinematically-correct Stereolithographic model


The Entomopter flaps wings like all creatures which fly, but with a new "twist"...


Innovative
Wing Kinematics
MAR
Mesoscaled Aerial Robot
DIRECTION OF FORWARD FLIGHT
0° TWIST
45° TWIST
+45° TWIST
F
R
REAR WING (R)
FRONT WING (F)
TORSIONAL AXIS
• Clever tandem X-Wing design is longitudinally stable.
• Wing dihedral results in roll stability even during flapping.
• 180° phasing of wings allows torsional resonance in airframe with stationary central fundamental node.
• Linear muscle drives wings with simple cam-follower.
• Wing flapping achieved with one moving part.
• Simple *autonomic wing flapping* reduces parts count and greatly enhances manufacturability.
DARPA DSO
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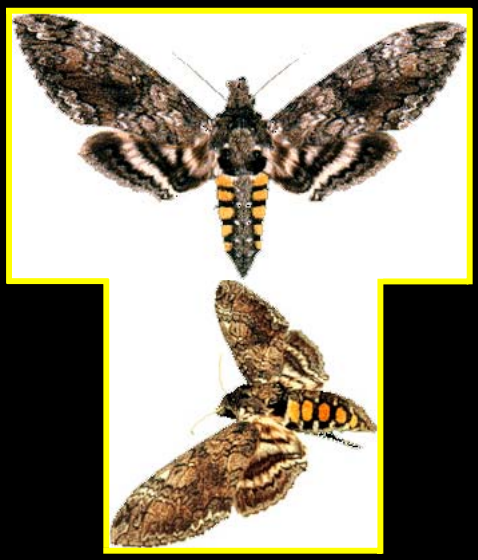
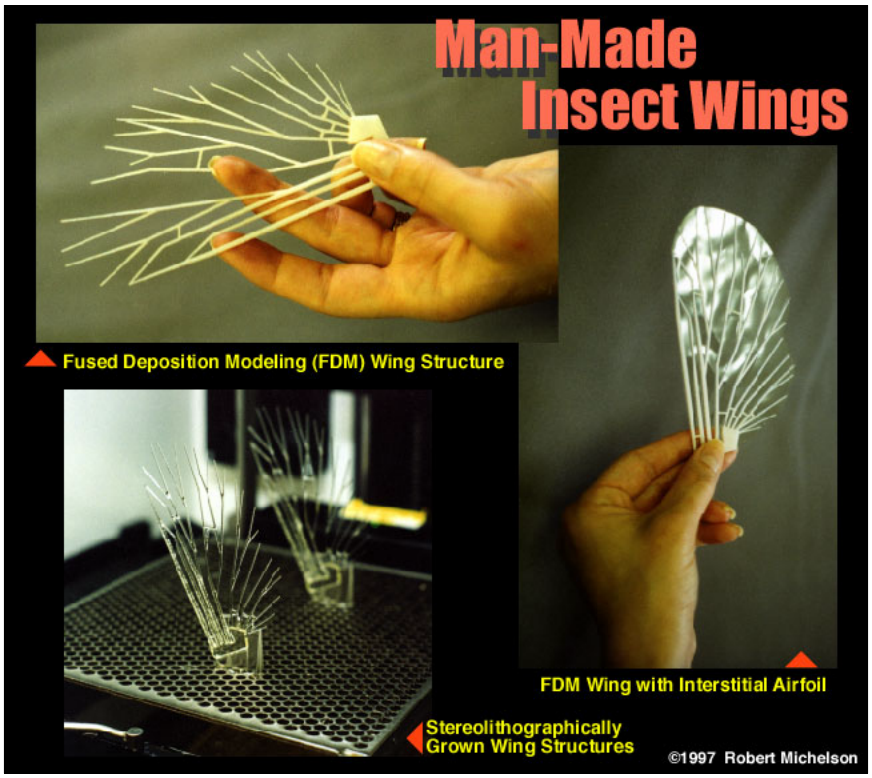
The Entomopter uses Resonanace just like insects and birds..

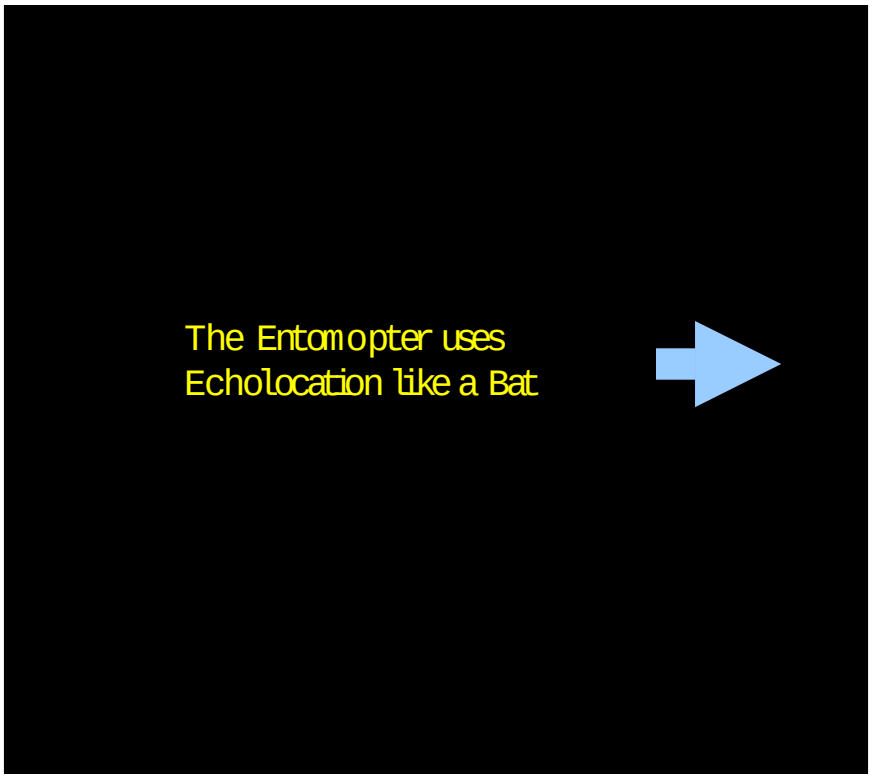
Entomopter biomimetic wing shape inspired by: Manduca sexta

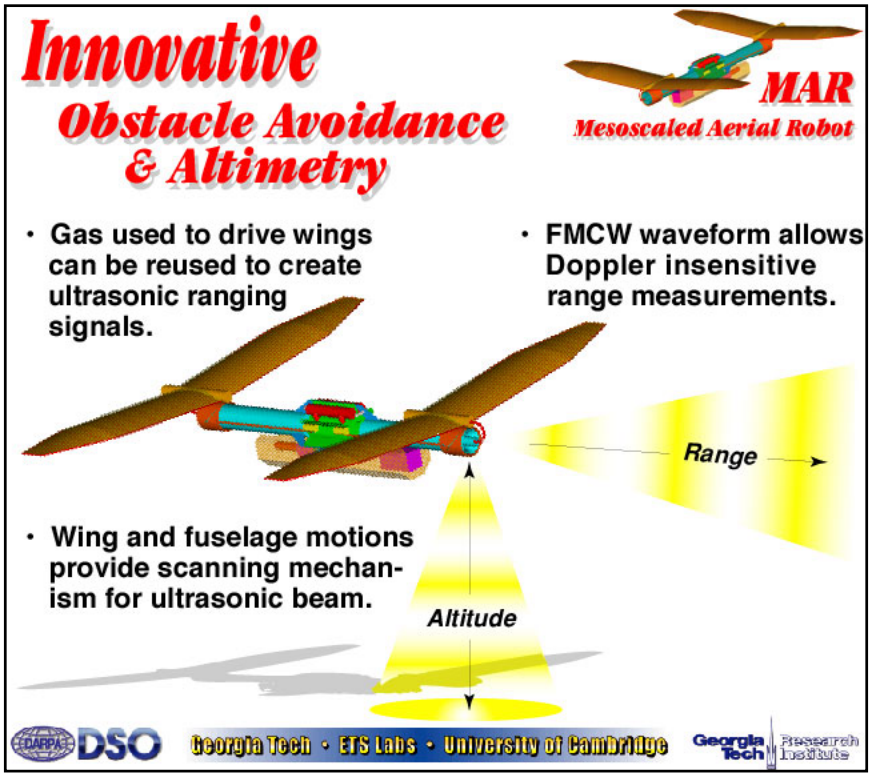
(the "Tobacco Hornworm", or "Hawkmoth")



The GTRI research team includes biologists from Cambridge University, England


Man-Made
Insect Wings
Fused Deposition Modeling (FDM) Wing Structure
FDM Wing with Interstitial Airfoil
Stereolithographically
Grown Wing Structures
©1997 Robert Michelson


The Entomopter uses
Echolocation like a Bat


Innovative
Obstacle Avoidance
& Altimetry
MAR
Mesoscaled Aerial Robot
• Gas used to drive wings can be reused to create ultrasonic ranging signals.
• FMCW waveform allows Doppler insensitive range measurements.
Range
• Wing and fuselage motions provide scanning mechanism for ultrasonic beam.
Altitude
DSO
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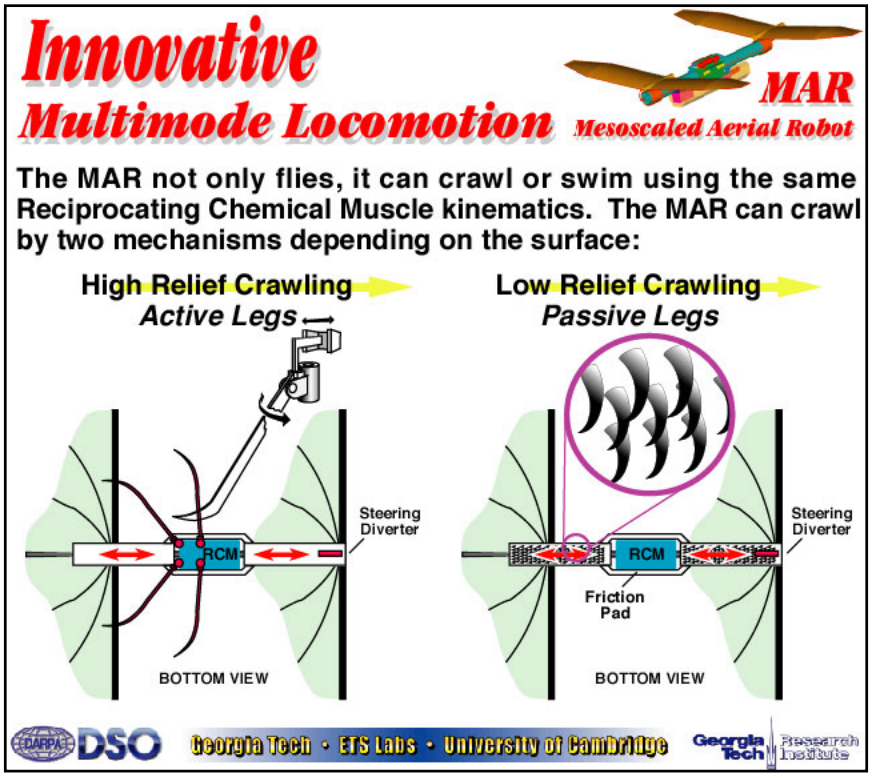
Multimode Entomopter: Flies and crawls as do all flying insects.


Innovative
Multimode Locomotion
MAR
Mesoscaled Aerial Robot
The MAR not only flies, it can crawl or swim using the same Reciprocating Chemical Muscle kinematics. The MAR can crawl by two mechanisms depending on the surface:
High Relief Crawling
Active Legs
Low Relief Crawling
Passive Legs
Steering Diverter
RCM
BOTTOM VIEW
Steering Diverter
RCM
Friction Pad
BOTTOM VIEW
DARPA
DSO
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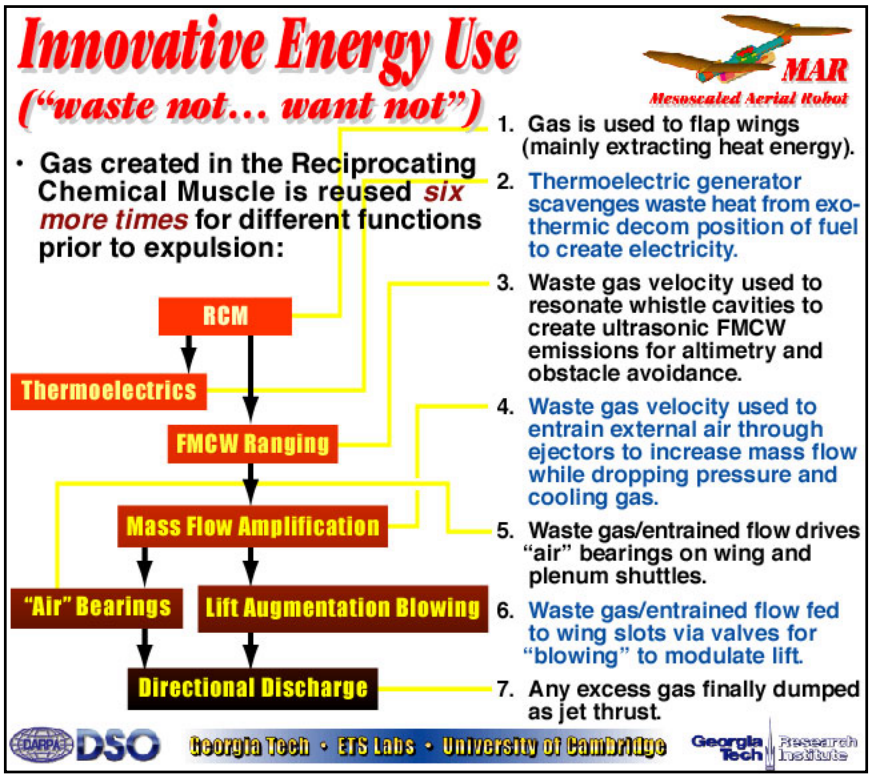
Innovative Energy Use
("waste not… want not")
MAR
Mesoscaled Aerial Robot
• Gas created in the Reciprocating Chemical Muscle is reused six more times for different functions prior to expulsion:
RCM
Thermoelectrics
FMCW Ranging
Mass Flow Amplification
"Air" Bearings
Lift Augmentation Blowing
Directional Discharge
1. Gas is used to flap wings (mainly extracting heat energy).
2. Thermoelectric generator scavenges waste heat from exo-thermic decom position of fuel to create electricity.
3. Waste gas velocity used to resonate whistle cavities to create ultrasonic FMCW emissions for altimetry and obstacle avoidance.
4. Waste gas velocity used to entrain external air through ejectors to increase mass flow while dropping pressure and cooling gas.
5. Waste gas/entrained flow drives "air" bearings on wing and plenum shuttles.
6. Waste gas/entrained flow fed to wing slots via valves for "blowing" to modulate lift.
7. Any excess gas finally dumped as jet thrust.
DARPA DSO
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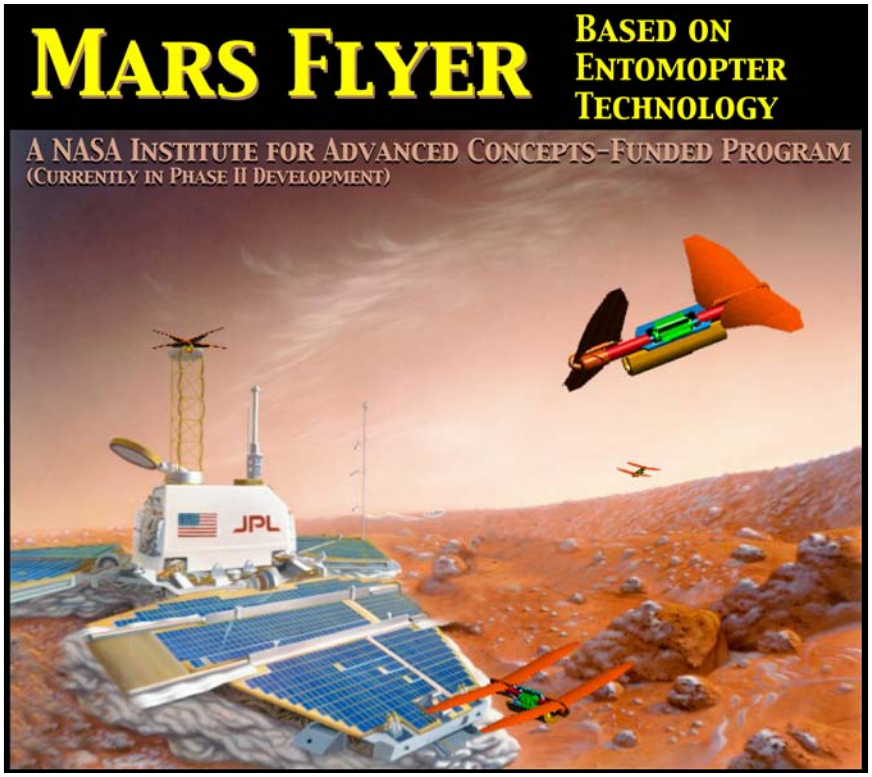
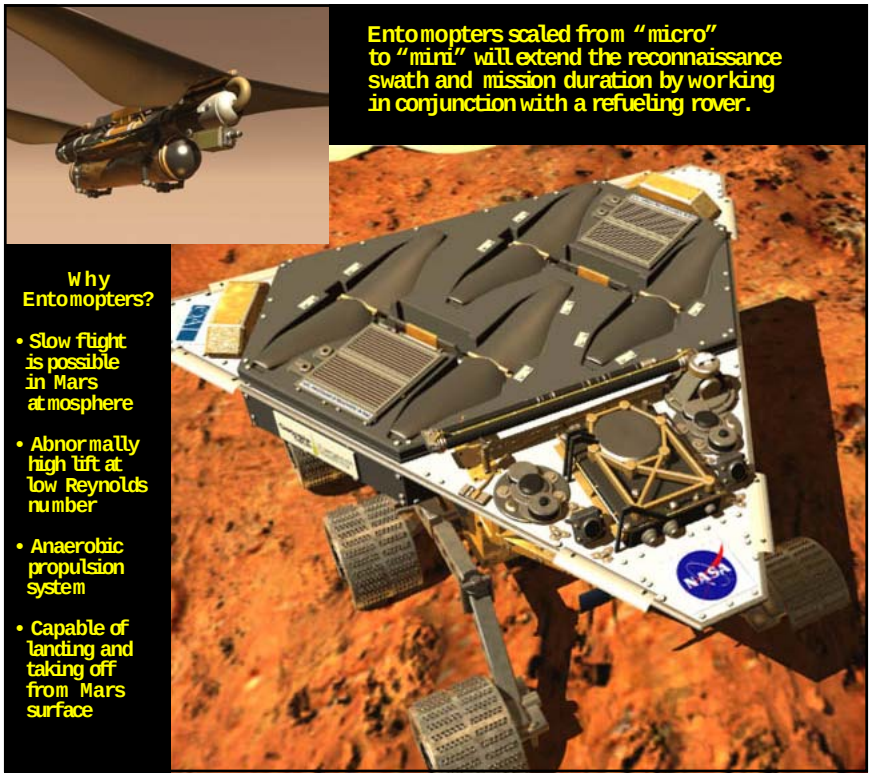

MARS FLYER
BASED ON ENTOMOPTER TECHNOLOGY
A NASA INSTITUTE FOR ADVANCED CONCEPTS-FUNDED PROGRAM
(CURRENTLY IN PHASE II DEVELOPMENT)
JPL


Entomopters scaled from "micro" to "mini" will extend the reconnaissance swath and mission duration by working in conjunction with a refueling rover.
Why Entomopters?
• Slow flight is possible in Mars atmosphere
• Abnormally high lift at low Reynolds number
• Anaerobic propulsion system
• Capable of landing and taking off from Mars surface
NASA


Entomopter-Based Mars Refueler Landing Sequence


End
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